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NOTES FROM THE PHYSICAL LABORATORY.

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Some New Methods for the Measurement of Self Inductance, Mutual Inductance and Capacity.

By H. A. ROWLAND and T. D. PENNIMAN.

In the *American Journal of Science*, December, 1897, and in *Phil. Mag.*, January, 1898, one of us published an account of a large number of new methods for the measurement and comparison of self-inductance, mutual inductance and capacity. Several of these methods have been tested in the Physical Laboratory of the University with great success, notably the methods for the *comparison* of the above quantities.

The methods involve the use of the electrodynamometer with an alternating current, and depend on one general principle—that is, that the deflection of the hanging coil of an electrodynamometer, if the hanging coil and the fixed coils of the electrodynamometer are originally at right angles, is proportional to the product of the currents in the hanging coil and the fixed coils, together with the cosine of the phase difference of the two currents. The dependence of the deflection on the cosine of the phase difference of the currents divides the methods into two general classes—methods in which there is a deflection; i. e., the cosine of the phase difference has a value; and methods of zero deflection, i. e., the cosine of the phase difference is equal to zero. The first class of methods gives the self-inductance or capacity in terms of resistance and b, i. e., 2π (the number of complete alternations per second of the current). These methods were very easy of application; the chief difficulty was the variation of b, as the current was generated in the power house of the University, where the engine was subject to great change of load. The presence of electric absorption also interfered with the accurate determination of the capacity of condensers. (See note on ABSORPTION, page 52).

The following method is an example of this class, and of the accuracy with which self-inductance can be determined even under these conditions. In this method the fixed coils of the electrodynamometer are in the main line or circuit, and the hanging coil is shunted off the main circuit around a small resistance, r. In the hanging coil circuit is placed a non-inductive resistance, R, with a self-inductance, L, under which condition the hanging coil will have a certain deflection when the current is flowing. They, R and L, are now removed, and a non-inductive resistance, R^1, is substituted, which is adjusted to give the same deflection as when R and L were in circuit. Under these conditions,

$$b^2 L^2 = (R^1 - R)\ (R + r).$$

By this method and similar methods given in the article cited, values of self-inductances were determined that agreed among themselves to within about 1 part in 100; i. e., the determinations were made with about the same degree of accuracy as b could be determined, on which quantity they directly depended. Taking into account absorption, capacity can be determined by the same method with about the same degree of accuracy. This method is easy to use, as it requires but one adjustment, R^1.

The methods for the comparison of the above quantities gave much more accurate results, as they are independent of the period of the current, the great cause of error in the measurement of the quantities. When care was taken to guard against all inductive and electrostatic action of the different parts of the apparatus on each other, the results derived by the different methods tried were remarkably good, notably the results obtained by the method for the comparison of two self-inductances. The connections for this method are made in this manner:

Let there be two coils of self-inductances, B_1 and B_2 placed together, and let the circuit pass through the coil B_2. From the main circuit, after it has passed through the coil B_2, the hanging coil of the electrodynamometer, having in circuit a self-inductance, L, and a resistance, R, is shunted around a small resistance, r. The coil B_1 is placed in circuit with the fixed coils of the electrodynamometer and a resistance, R^{11}.

The condition, then, for zero deflection when the current is flowing is

$$\frac{L}{B_1} = \frac{R + r}{R^{11}}$$

Using this method and taking B_1 as a standard equal to 1 Henry, several coils were compared with B_1, both singly and in series. To show with what accuracy self-inductances of different amounts can be compared, a few values are given for two periods. The coils being compared with B_1 as a standard

	$n = 40$		$n = 133$		
COILS.	Results found by direct measurem't.	Sums and differences of direct measurem't.	Results found by direct measurem't.	Sums and differences of direct measurem't.	Sums and differences.
P_1	.5664	.5663	.5653	.5648	$(C + P_1) - C = P_1$
C	1.3050	1.3049	1.3034	1.3029	$(C + P_1) - P_1 = C$
$C + P_1$	1.8713	1.8714	1.8682	1.8677	$C + P_1$

These are good cases of agreement, and show the accuracy of the method for the comparison of self-inductances of different amounts, when care is taken to eliminate heating and electrostatic action of the resistance and leads.

It will be noticed that the value of the self-inductance for the two periods is different; this was due to the electrostatic action of the turns of the coils on each other, and therefore could not be avoided.

When equal self-inductances are to be compared, the accuracy depends only on the sensitiveness of the instrument to changes in $R+r$; and in the arrangement used in our experiments, the electrodynamometer was sensitive to changes of about 1 part in 10,000 in $R+r$. Therefore the construction of standard self-inductances that will agree with each other to within 1 part in 10,000 is feasible by this method.

Electric Absorption in Condensers. By H. A. Rowland and T. D. Penniman.

The theory of electric absorption and its effect on the capacity of condensers has been developed, and experiments have been carried out to test the theory and results. A short account of the theory was given in the *American Journal of Science*, December, 1897, but since that time a method for the direct measurement of the effect of absorption has been devised, and it is of interest to note the agreement of the results derived by two independent methods.

The condensers used in the experiments were constructed of parallel plates separated by paraffined paper or mica; that is, by a non-homogeneous medium; but Maxwell (El. and Mag., § 329) has shown that absorption is a necessary condition in a condenser whose surfaces are separated by a non-homogeneous medium.

Professor Rowland, starting with the formula as given by Maxwell, has developed the theorem for the case when the electromotive force is periodic, and has deduced the "correction" due to absorption. The formula is thus developed.

Since the insulating plates of the condenser are not homogeneous, they can be considered as made up of strata. The current through any stratum of thickness 1 cm. is

$$\bar{u} = \frac{X}{r_1} + \frac{1}{4\pi K_1}\frac{dX}{dt}$$

when $\bar{u} \equiv$ current per square centimeter.
$r_1 \equiv$ specific resistance per unit of volume.
$K_1 \equiv$ *inverse* of the dielectric constant.
$X \equiv$ electromotive force on the two sides of the stratum.

If the electromotive force is periodic,

$$X = X_1\, \epsilon^{ibt}$$

Where $b = 2\pi$ (complete number of alternations per second). Substituting, we have

$$\bar{u} = \left(\frac{1}{r_1} + \frac{ib}{4\pi K_1}\right)X$$

$$\therefore\quad X = \frac{\bar{u}}{\frac{1}{r_1} + \frac{ib}{4\pi K}}$$

If there are several strata of different thicknesses, a_1, a_2, a_3, etc.,

$$X^1 = \bar{u}\left(\frac{a_1}{\frac{1}{r_1} + \frac{ib}{4\pi K_1}} + \frac{a_2}{\frac{1}{r_2} + \frac{ib}{4\pi K_2}} + \text{etc.}\right)$$

where X^1 equal the sum of the electromotive forces on the strata. Expanding and collecting the terms, the equation reduces to the form:

$$X = \bar{u}\left(R + \frac{1}{ibc}\right)$$

where

$$R = \frac{B_0}{b^2} - \frac{B_2}{b^4} + \frac{B_4}{b^6} - \text{etc.}$$

$$\frac{1}{c} = A_0 - \frac{A_2}{b^2} + \frac{A_4}{b^4} - \text{etc.}$$

the values of the constants being as follows:

$$B_0 = \frac{a_1}{r_1 K_1} + \frac{a_2}{r_2 K_2} + \frac{a_3}{r_3 K_3} + \text{etc.}$$

$$B_2 = (4\pi)^2\left\{\frac{a_1}{r_1^3\, K_1^4} + \frac{a_2}{r_2^3\, K_2^4} + \text{etc.}\right\}$$

$$B_4 = (4\pi)^4\left\{\frac{a_1}{r_1^5\, K_1^6} + \frac{a_2}{r_2^5\, K_2^6} + \text{etc.}\right\}$$

etc.

$$A_0 = 4\pi\left\{\frac{a_1}{K_1} + \frac{a_2}{K_2} + \frac{a_3}{K_3} + \text{etc.}\right\}$$

$$A_2 = (4\pi)^2\left\{\frac{a_1}{r_1^2\, K_1^3} + \frac{a_2}{r_2^2\, K_1^3} + \text{etc.}\right\}$$

etc.

From the above it appears that a capacity having absorption acts in a circuit as a capacity with a resistance in series with it. The resistance is called "absorption resistance," and appears to vary with b, i. e. with the number of alternations. The capacity proper, i. e. c, will be independent of b if the number of alternations is great.

In the determination of the capacity of two condensers, 2 and 3 microfarads in parallel by Method 1 (see Note on the Measurement and Comparison of Self-Inductance, Mutual Inductance and Capacity), great variations were found in the deduced values of the capacity (using the ordinary formulae and treating a condenser as if it had capacity only), depending on the resistance in circuit and on the period, the variations being between wide limits, as is shown by the following example:

$n =$ *number of complete alternations per second.*	$R \equiv$ *resistance in circuit with the condensers.*	$C \equiv$ *deduced value of the capacity.*
131.1	21.7	5.47
"	1021.7	4.51
53.3	21.7	6.38
"	1021.7	4.86
31.9	21.7	7.46
"	1021.7	4.92
14.	21.7	10.79
"	1021.7	4.87

But since the condensers possess absorption, and as the effect of absorption as shown in the formula above is that of an added resistance in series with a capacity, therefore the deduced values of the capacity for any particular period should be constant for all values of R, if the value of R is increased by a constant quantity A, the "absorption resistance," depending on the period. Doing this, and correcting the results of which the above are examples, a fair agreement is found for the "true" capacities for the periods used. In the tables below are collected the average corrected values of the capacity, together with n, and A the absorption resistance in ohms.

Capacity in microfarads.	4.94	4.96	4.96	4.64
n	131.1	53.3	31.9	14.
A *in ohms.*	5.19	20.5	34.09	139.62

In the table the capacity is nearly independent of n, except when $n = 14$; but this may be caused by an error in determining n on which the capacity depends directly. A shows remarkable variation with n.

A, however, can be measured directly, and this was done for several condensers, including those used above, so that it was possible to compare two independent determinations of the same quantities.

The method for the direct measurement of absorption resistance involves the use of the Wheatstone bridge and an electro-dynamometer with an alternating current.

If the fixed coils of an electro-dynamometer are placed in one arm with a condenser, and if the hanging coil is placed in the cross connection of the bridge, and a periodic electro-motive force is applied to the terminals of the bridge, the condition that there is no deflection of the hanging coil is that

$$R_{\prime}R'' = R'R_{\prime\prime} - \left(b^2 l L_{\prime} - \frac{l}{C}\right)\frac{R''(R' + R'')}{R'(R'' + R_{\prime\prime}) + r(R' + R'')}$$

when $R_{\prime} \equiv$ resistance of arm with condenser.
$R', R'', R_{\prime\prime} \equiv$ resistance of the other arms.
$r \equiv$ resistance of the cross connection.
$L_{\prime} \equiv$ self-inductance of fixed coils of electro-dynamometer.
$l \equiv$ self-inductance of hanging coil of electro-dynamometer.
$C \equiv$ capacity of condenser.

Since $L_{\prime}$ is small, the formula reduces to the form:

$$R_{\prime}R'' = R'R_{\prime\prime} + \frac{l}{C}\,\frac{R''(R' + R'')}{R'(R'' + R_{\prime\prime}) + r(R' + R'')}$$

The resistance $R_{\prime}$ was made up of the ohmic resistance of the arm of the bridge and the absorption resistance.

Determining R_1 by this method, and knowing its ohmic resistance, the absorption resistance A was found. Using this method, for the condensers used above, A was found for a few periods, and it can be seen from the accompanying table how the values determined by the two methods agree.

n	134.	131.1	57.6	56.6	53.3
Method I.		5.19			20.5
Direct measurement.	5.30		21.6	22.2	

The values as determined by Method I. should be somewhat less than those determined by direct measurement. In Method I. there was practically no heating, while in the method of direct measurement there was considerable rise of temperature, due to the comparatively large current flowing through the condensers; and it was found that the absorption resistance increased rapidly with the temperature.

The above table seemed to confirm the assumption that the effect of absorption in a condenser is that of an added resistance in series with it, and this is still further confirmed—taking into account the effect of rise of temperature on absorption resistance—by some experiments performed with two condensers, each a $\frac{1}{3}$ microfarad. For one, A was equal 3.144 ohms; A for the other was equal 7.116 ohms. Calculating from these two values what the absorption resistances should be for the two condensers in series and in parallel, they are 10.26 ohms and 2.20 ohms, respectively. The absorption resistances for the condensers in series and in parallel, as found by direct experiment, in the two cases are 10.49 ohms and 2.79 ohms—somewhat larger than they should be, owing to the previous heating, but still showing considerable agreement.

Some Notes on the Zeeman Effect. By J. S. Ames, R. F. Earhart and H. M. Reese.

In our investigation of the effect of the magnetic field on radiations in the ether, we have been led to study certain variations from the phenomena discovered by Zeeman, which seem to be worthy of note. Up to the present we have studied the effect of a magnetic field upon the spark-spectra of magnesium, iron, cadmium and zinc. The research is by no means completed, but having discovered several new effects we think it well to publish them at present, and to defer until later a full discussion of the phenomena.

Our apparatus has been the small concave grating of the Physical Laboratory, which has a radius of curvature of about eleven feet. The grating is ruled with 15,000 lines to the inch and is five inches in width. The magnetic field has been produced by an ordinary form of electro-magnet, but we have made no attempt to measure the intensity of the field, because our object has not been to establish numerical relations. The field, however, was strong enough to produce a separation in the case of iron of about a tenth of an Ångström unit, and the definition has been most satisfactory. The method of use was to introduce between the spark and the slit a Nicol's prism and quartz lens, and to photograph the resulting spectra along the middle of the photographic plate, then turning the Nicol's prism through 90°, and at the same time turning a shutter which is placed in front of the photographic plate to expose the two edges of the plate to the new radiation coming through the Nicol's prism. By this method we secure on the same plate the components of the vibrations polarized along the lines of force and at right angles to them.

We have studied the effect of the magnetic field upon the iron spectrum from wave-length 3400 tenth metres to wave-length 4300, and in this region have noticed that all the lines, with certain exceptions to be noted, are influenced in the way discovered by Zeeman. In particular, when the radiation at right angles to the magnetic field is studied, each line in the spectrum is broken up into three, the central component being plane polarized, with its vibrations along the lines of force; the two side components being plane polarized at right angles to this, their vibrations being at right angles to the field of force.

We have observed, however, that three lines, of wave-length 3587.13, 3733.47 and 3865.67, are affected in the opposite way; that is, the line is a triplet when viewed at right angles to the magnetic field, but the central component is so polarized that its vibrations are at right angles to the field, and the two side components have their vibrations along the field.

Four lines, at 3746.06, 3767.34, 3850.12, 3888.67, have, so far as our indications go, no modification produced whatever. The lines at 3722.72 and 3872.64 are so modified as to be quadruplets, the central component which has its vibrations along the lines of force being a close double. There are several other lines concerning which we have doubt, but most of the others examined are clearly modified in the way described by Zeeman. We have noted too that the separation of the side components of the triplets seems to be most irregular; lines whose wave-lengths differ by only a few Ångström units have displacements which differ by 20 per cent. at least. In short, there seems to be no regularity in the separations produced. (Several of the above effects have been observed by other investigators.)

In studying the spectrum of cadmium we have observed that the lines at 4678.37, 4800.09, 5086.06, which belong to the "second subsidiary series," and the lines at 3467.76 and 3613.04, which belong to the "first subsidiary series," are all modified in the normal manner; that is to say, in the manner described by Zeeman, and by amounts which are no greater than for iron, but that there seems to be no regularity in the separations produced, either between the two series or between the lines of any one series.

We have been unable to extend our investigation into the extreme ultra violet owing to the fact that the Nicol's prism which we used in order to separate the components, absorbs the waves beyond 3400.

In the study of the spectra of zinc and of magnesium, we have not yet obtained results which are worthy of note.

The Effect of Alternating Current Wave-Forms on Transformer Losses. By Louis Duncan, W. L. Hodges, F. B. Keidel, and E. Frank.

The currents represented by waves of different shapes, as shown in the figures, were obtained by superimposing a third harmonic upon a fundamental wave. This was effected by joining "in series" two dynamos connected by a chain running on sprocket wheels so proportioned as to give the third harmonic relation. By changing the fixed position of one of the sprocket wheels, the third harmonic could be superimposed in any position.

The two machines used were an eight-pole Siemens alternator, running at a speed of 540 revolutions per minute, generating an alternating current of 36 cycles per second, and a bi polar continuous current machine made by the United States Company. The armature and brushes of the continuous current machine were revolved at such a speed as to give an alternating current of 12 cycles per second.

A Westinghouse (No. 8) transformer was used. The transformer was designed for a current of 8000 cycles per minute.

The secondary consisted of four coils; and a difference of potential of 1050 volts across the primary terminals produced a difference of potential of 100 volts across the secondary terminals. In the experiment the four coils of the secondary were connected in series.

The watts consumed were measured by an electro-dynamometer calibrated as a wattmeter. The "idle current" was measured by a low-reading Thompson alternating ammeter.

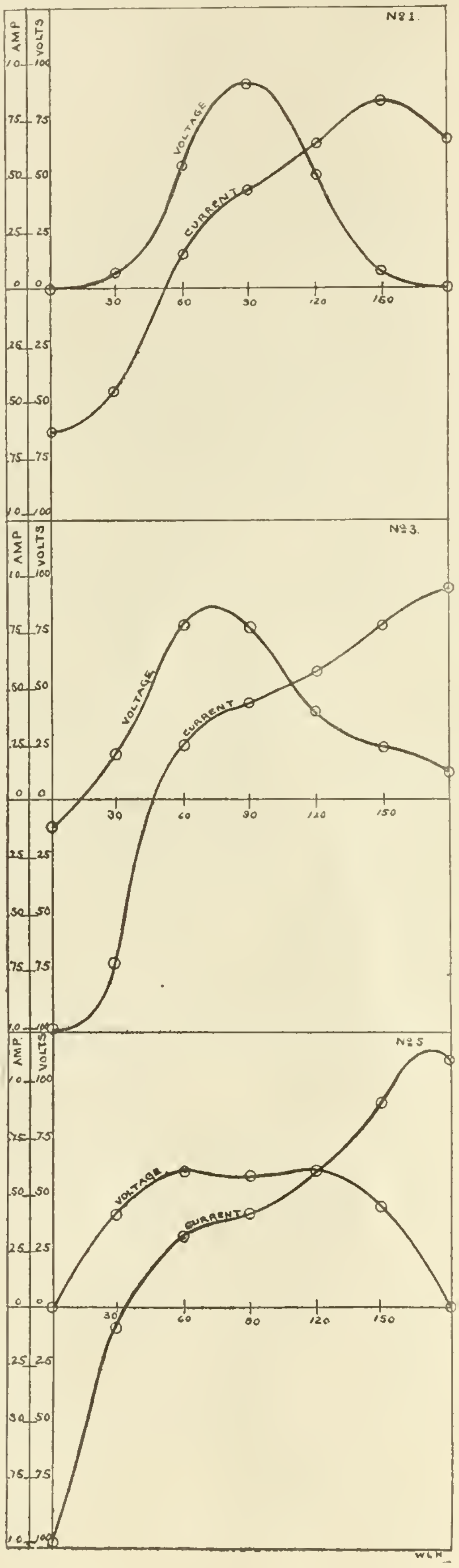
The instantaneous values of voltage and current were obtained by the instantaneous contact method, using calibrated electro-dynamometers.

In the curves shown the degrees refer to the zero point of the fundamental wave, the position of which was not changed.

Eight curves of different shapes were obtained, the third harmonic being advanced 15° in each case (with an advance of 120° the curves repeat themselves). A sine wave (No. 9) was also used.

No. of Curve.	1	2	3	4	5	6	7	8	9
Idle Current (amp.)............	.565	.625	.645	.655	.655	.615	.574	.545	.650
Watts consumed (true watts)	13.5	14.5	16.5	18.35	19.5	18.25	17.5	15.0	17.0
Remarks............	Peaked.				Flat.				Sine.

Above is a summary of the results obtained. By means of a standard voltmeter the potential across the terminals of the transformer was kept constant at 50 volts.



From the results given above, it is seen that the watts consumed by the transformer with the "peaked" wave (No. 1) are only 69.3 per cent. of those consumed by the "flat" wave (No. 5). The "idle current" is also much less in the case of the "peaked" wave.

The three sets of curves shown are the "peaked" wave (No. 1), the "flat" wave (No. 5), and an intermediate wave (No. 3).

A Recalculation of Griffiths' Mechanical Equivalent of Heat, based on Kahle's Determination of the Absolute Electro-Motive-Force of a Clark Cell and of the Electro-Chemical Equivalent of Silver. By F. A. Wolff, Jr., Ph. D., Office of U. S. Standard Weights and Measures, Washington, D. C.

The purely mechanical methods which have been employed for the determination of the mechanical equivalent of heat all give results agreeing with Rowland's original value within the probable limits of error. Recently Griffiths, and Schuster and Gannon, have obtained values by electrical methods differing appreciably from the mean of the above.

The only differences between the two methods, aside from the experimental details and the measurement of temperature, arise from the different methods of measuring the energy supplied to the calorimeter. This is measured directly in the mechanical methods, while in the electrical methods it is measured in terms of the absolute units of current, resistance, and electro-motive-force, which are based on the mechanical units.

All possible sources of error in both methods have been carefully scrutinized. Rowland's[1] thermometers have been compared with Tonnelot thermometers, which in turn have been compared with the nitrogen standard of the International Bureau. In addition, Rowland's thermometric scale has been compared with the platinum scale employed by Griffiths.[2] Eliminating all differences arising from different thermometric standards, the recalculated values of Rowland were found to differ from those of Griffiths by a constant amount of about 1 part in 400 at all temperatures, while the uncorrected values did not show a constant difference throughout the range of temperature employed.

While there is very slight possibility of an appreciable error in measuring the electrical quantities involved in Griffiths' determination in terms of the accepted standards of electro-motive-force and resistance, yet we are not sure that these standards are themselves correctly known. Therefore, at the Toronto meeting of the British Association, 1897, the Committee on Electrical Standards received an appropriation to redetermine the absolute electro-motive-force of the Clark cell and the electro-chemical equivalent of silver; and their results are anxiously looked for.

This redetermination has, however, recently been made at the Reichsanstalt by Dr. Kahle by means of an electro-dynamometer designed by the late Professor von Helmholtz.[3]

The Clark cell was kept at the temperature of melting ice during the experiment, and the relation between its E. M. F. at that temperature and at 15° C., the standard temperature, was also determined.

The value obtained for the German H–standard was

$$E_{15} = 1.4325 \text{ absolute volts.}$$

Fortunately, a direct comparison was made in 1892 between the Cambridge standard cell to which Griffiths' results are referred and the German standards. The results obtained by Dr. Kahle and Professor Glazebrook[4] showed that the Cambridge standard had an E. M. F. .0004 volts greater than the German standard.

Hence,

$$\text{Cambridge}_{15} = 1.4325 + .0004 = 1.4329 \text{ absolute volts.}$$

In Griffiths' determination the value assigned to the Cambridge standard was 1.4342, as determined by Glazebrook and Skinner.

The electro-motive force of the standard being taken too high, we obtain a value of J., the Mechanical Equivalent of Heat, too high; and to reduce we must multiply Griffiths' value by

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[1] Day, Univ. Circ., June, 1897.

[2] Waidner and Mallory, Univ. Circ., June, 1897. Note in this Circular, also.

[3] Zeitsch. f. Inst. k., Vol. 17, p. 144; Wied. Annal, Vol. 59, p. 532.

[4] B. A. Rep., 1892; Phil. Trans. A., 1892, p. 605.

$$\left(\frac{1.4329}{1.4342}\right)^1 = .99819$$

Correcting Griffiths' value for J. at 20° (4193.2×10^4) we obtain 4185.6.

The units of reference chosen by Schuster and Gannon[1] were those of current and E. M. F.

The value of *their* Clark cell was assumed to be 1.4340, and the electrochemical equivalent of silver was taken to be 1.118 mgs. per ampere per sec. No direct comparisons between their cell and the Cambridge standard have been recorded, but their results can be reduced to the above standard, assuming that their cell does not materially differ from the German standard.

Kahle found a difference of about 1 part in 1000 in the electro-chemical equivalent of silver, using fresh and old solutions. For fresh solutions he found the value 1.1182, taking the E. M. F. of a Clark cell 1.4325 as found by him.

Correcting Schuster and Gannon's result for J. at 20° C., 4191×10^4 ergs. we obtain

$$4191 \times \frac{1.4325}{1.434} \times \frac{1.118}{1.1182} = 4185.9$$

No allowance has been made for possible differences in standards of resistance, which can, however, introduce no great corrections, although it seems that the Reichsanstalt standard of resistance, the mean of a number of mercury standards, differs at present by .01 per cent. from the Cambridge International Ohm. *defined* by the relation

$$1 \text{ B. A. unit} = .9866 \text{ Int. Ohm.}$$

To summarize, the old and corrected values of the mechanical equivalent of heat at 20° C. are given below:

	Old.	*Corrected.*
Rowland............................		$4183. \times 10^4$ mgs.
Griffiths............................	4193.2	4185.6 "
Schuster and Gannon...........	4191	4185.9 "

Another method of comparison would be to substitute Rowland's value in Griffiths' result and calculate the E. M. F. of the Cambridge standard.

$$\begin{aligned} &\text{This gives } E_{15} = 1.43245 \text{ absolute volts,} \\ &\text{against } \underline{E_{15} = 1.4329} \text{ as determined by Kahle.} \\ &\text{Diff.} = \ .00045 = .03 \text{ per cent.} \end{aligned}$$

Kahle's value of the absolute E. M. F. of the Clark cell therefore seems to accord better with results obtained than the accepted value, 1.434 at 15. C.

NOTE.—One of Schuster and Gannon's Secondary Standards, No. 97, was compared in 1891 by Glazebrook and Skinner, with their own standards. The differences in electromotive-force found ranged between + .0027 volt and — .0017 volt; and hence no definite conclusions can be drawn as to the exact relation between Schuster and Gannon's standard cell and the Cambridge standard. (See *Phil. Trans.*, 1892, Vol. 183 A, p. 590).

The Energy Spectrum of an Absolutely Black Body.

By C. E. MENDENHALL and F. A. SAUNDERS.

In the Johns Hopkins *University Circulars* for June, 1897, we gave a preliminary note on the energy spectrum of a black body, as experimentally realized by a uniformly heated enclosure. This work has been repeated and extended with improved apparatus during the present year.

The form of body used was a hollow metal cylinder of length 17.5 cm., outside diameter 14 cm., and inside diameter 12.5 cm., with a vertical slit in its side 3 cm. high by 0.6 cm. wide, through which passed the energy to be measured. For low temperatures, up to 500° C., a double-walled body was used, between the walls of which a boiling liquid of suitable boiling point could be kept circulating, while for higher temperatures the body was made of half-inch grey cast iron and was mounted in a furnace of fire clay, heated by two blasts, one from above and the other from below. It is, of course, extremely important to produce a uniform temperature over the entire surface of the body, and by a suitable adjustment of the two blasts this ideal condition was nearly reached. The temperature was measured by means of platinum-platinum-iridium thermocouples which were inserted by means of two tubes entering the body from above; and readings were made at four points in the body, at two points near the top and bottom. An extreme variation of 30° C. was unusual, but occurred occasionally at the high temperatures, while as a rule the variation was about 15°; for the lower temperatures for which the furnace was used the variation was seldom 20°, and was generally about 10°, while when the body was heated by boiling liquids there was no perceptible variation. The alterations of temperature during the taking of a curve were usually very small, and in the high temperature work the curves were all repeated, and an average curve was taken, by which means it was thought that the effects of temperature variation were nearly eliminated.

The spectrometer slit was 1.5 mm. in width and produced, by means of a rock salt prism and lens, an image just covering the bolometer strips, which were 1 mm. in width and subtended at the axis of the instrument an angle of 5 minutes. The galvanometer was made especially for this work according to the Rowland pattern of Thomson four-coil instrument, and had a resistance of about 4 ohms; the magnet system used was made from ordinary watch hair-springs, the magnets being about 1 mm. in length and 8 in number, and the weight of the whole system, including the mirror, was 3.5 milligrams. This gave a deflection of 1 mm. at a distance of a metre for a current of $1.2 . 10^{-10}$ amperes and a complete period of 10 seconds. This sensitiveness was found quite sufficient, and gave for the higher temperatures a measurable deflection at a wave-length of 20 μ; but in the lower temperature work the system was never astatic enough to be at rest, even when the observations were made between three and five o'clock in the morning. The sensibility of the bolometer-galvanometer combination was tested by throwing in or out a small shunt in the bridge circuit and observing the deflection produced. In this way curves taken on different nights could be reduced to the same scale of sensibility.

The results show a shift of the maximum energy between the temperatures 1130° C. and 204° C. from 2.16 μ to about 5.0 μ, while the maxima for some of the other curves fall as follows: for 844° C., about 2.5 μ; for 554° C., about 3.1 μ, and for 292° C., about 4.4 μ. The curves not yet having been corrected for the impurity of the spectrum, however, these values can only be given as provisional; and the exact positions and amounts of the maxima are also difficult to determine owing to the fact that the absorption bands due to water vapor and to carbon dioxide falling at about 2.7 μ, and in our curves extending from 2.2 μ to 3 μ, cut off the tops of several of the high temperature curves. The carbon dioxide band at 4.3 μ, which extends from 3.6 μ to nearly 5 μ, disfigures in a similar manner the lowest curves obtained.

The curves drawn with galvanometer deflections as ordinates, and minimum deviations as abscissae, have been integrated to obtain the total radiation, and the results compared with the recent work of Lummer and Pringsheim (Wiedemann's Annalen, Jubilee Volume, Dec., 1897, p. 395), and with the formula of Stefan. Our results show on the whole a fair agreement with the formula:

$$\text{Total radiation} = C\,(T^4 - 292^4),$$

in which T is the absolute temperature and C a constant, although the radiation for the low temperatures is less than the formula would lead us to expect—a result which is in accord with the observations of Lummer and Pringsheim.

A Recalculation of Rowland's Values of the Mechanical Equivalent of Heat.

By C. W. WAIDNER and F. MALLORY.

(SECOND PAPER,—*in continuation of Note in Circular, No. 130, p. 42.*)

In order to account for the differences in the values of the Equivalent obtained by experimenters using the mechanical and electrical methods, the electrical methods apparently giving higher values, a comparison of the standards of thermometry used by the different observers was undertaken by the authors.

Rowland's temperature measurements were made with three Baudin thermometers (Baudin 6163, 6165, and 6166), which he had previously compared with an air thermometer. The temperature measurements upon which Griffiths' experiments depend, were made with platinum thermometers whose reduction to the air scale was known from a previous comparison of the platinum and air thermometer by Callendar and Griffiths; subsequently a Tonnelot thermometer standardized at the International Bureau of Weights and Measures was compared with the platinum air scale so that Griffiths was enabled to give his values on the Paris nitrogen scale. The experiments of Schuster and Gannon are based on the Paris nitrogen scale. Both Griffiths, and Schuster and Gannon, used electrical methods for the determination of the mechanical equivalent.

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[1] Schuster and Gannon, Proc. Roy. Soc., Vol. 57, p. 25.

Shortly after the publication of the *University Circulars* for June, 1897, in which a short account of our comparisons was given, some further comparisons were made between Rowland's mercury thermometers and the Callendar-Griffiths platinum thermometer. A comparison of the platinum thermometer was then made, by Dr. W. S. Day and the authors, with a Tonnelot thermometer which had been standardized at the Bureau International, and whose indications could therefore be reduced to the Paris hydrogen and nitrogen scales. The results of this comparison are shown by curve A below, where ordinates represent the corrections to be added to the Callendar-Griffiths air scale to reduce to the Paris nitrogen scale. The agreement between these two scales, the former based on measurements made with a constant pressure air thermometer, the latter on measurements with a constant volume gas thermometer, is certainly as close as we have any reason to expect when we consider the difficulties of gas thermometry. The connection between the different scales of temperature (that of Rowland, Callendar-Griffiths, and Paris) was thus found, so that Rowland's values of the mechanical equivalent could be brought into comparison with those of Griffiths, and Schuster and Gannon.

The results of the comparison of these thermometers can best be shown by means of the following curves. Abscissae represent temperatures on the centigrade scale, and ordinates the corresponding corrections that must be added to Rowland's scale (air and absolute) to reduce to the Callendar-Griffiths, Paris nitrogen, or Paris hydrogen scales.

I. Rowland's air scale to Callendar-Griffiths' air scale.
II. Rowland's absolute scale to Callendar-Griffiths' air scale.
III. Rowland's absolute scale to Paris nitrogen scale.
IV. Rowland's absolute scale to Paris hydrogen scale.

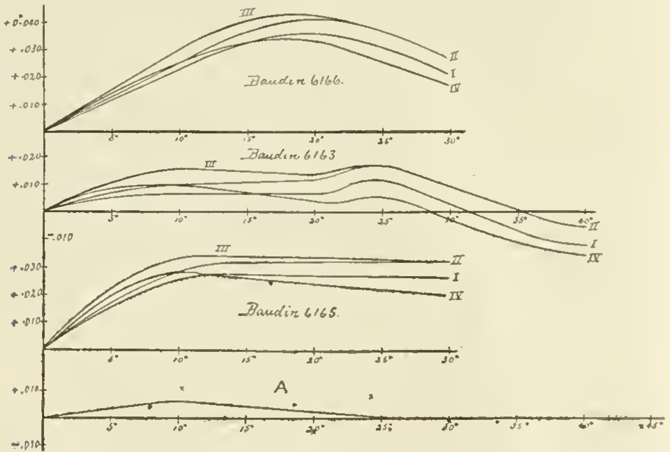


Plate I.

The resulting changes in Rowland's values of the mechanical equivalent of heat, when these are reduced to the Paris nitrogen scale, are shown by the following curves.

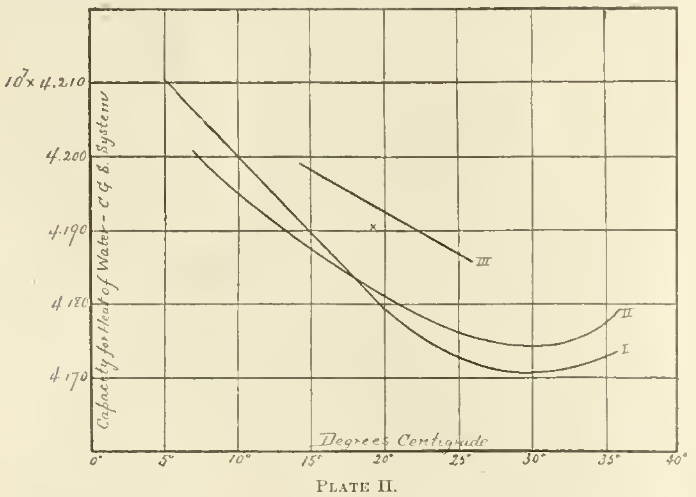


Plate II.

I. Rowland—original Absolute Scale.
II. Rowland—reduced to Nitrogen Scale.
III. Griffiths—Nitrogen Scale.
X. Schuster and Gannon—Nitrogen Scale.

As will be seen from these curves, the changes in Rowland's values are small, amounting to a decrease of about 1 part in 800 at 10°C., the value at about 17° remaining unchanged, while those at 20° and 25° are slightly increased. For the sake of comparison, the results of Griffiths, and those of Schuster and Gannon, are also given. The variation of the specific heat of water with temperature between 15° and 25°, when Rowland's values are referred to the Paris nitrogen scale, is practically identical with that given by Griffiths' curve. This suggests at once that an explanation of the differences between the mechanical and electrical determinations of the mechanical equivalent must be sought in the energy measurements.

In Rowland's experiments an error in the energy measurements may be due either to an error in the diameter of the torsion wheel of his calorimeter or to the system of weights employed. Inasmuch as the diameter of the torsion wheel was measured many times by comparison with two standard metre bars, each of which had been compared with the Coast Survey and other standards, the possibility of an error sufficient to account for the observed differences between the mechanical and electrical determinations must be sought elsewhere. Turning to the question of the weights used in these experiments, we see that it is not necessary that they be correct absolutely with the standards, if they are only relatively correct, as the formula for the mechanical equivalent contains a weight in both numerator and denominator; on the other hand, if they were not correct relatively, we should hardly expect to find the almost constant difference between the determinations of Griffiths and those of Rowland (reduced to nitrogen scale) throughout the range 15° to 25° C. The evidence accumulated thus far would, we believe, suggest as a possible explanation of these differences a still undiscovered error in the system of electric units employed. This, indeed, in the light of the enormous and painstaking work which serves as the basis of these units, is not probable, but, considering the difficulties encountered in the standards of electromotive force and current, it is not altogether impossible. The enormous experimental evidence which served as the basis of the international ohm, together with the recent confirmation of the accuracy of this unit, renders it almost certain that the discrepancy need not be looked for in this direction. (See article by Dr. F. A. Wolff, in this Circular, page 54.)

Notes on the Concave Grating.

By S. Alfred Mitchell.

General Theory.

The general theory of the concave spherical grating has been investigated by Rowland (*Phil. Mag.*, Vol. XVI, p. 197, and *Amer. Jour. Sci.*, (3), 26, 1883); by Glazebrook (*Phil. Mag.*, Vol. XVI, 1883); by Mascart (*Jour. de Physique* (2) 2, 1883); and by Kayser (Winkelmann, *Handbuch der Physik*, p. 408).

The following treatment is one which, starting from a perfectly general condition, is true for every form of grating ruled with equal spaces. By introducing the condition that the ruled surface is a portion of a sphere, the general equation of the concave grating is obtained.

From the general theory of gratings (Rayleigh, "Wave Theory of Light," § 14, *Ency. Brit.*, p. 437) we know, if we have a grating ruled with equal spaces along the chord on any surface, that

$$\lambda = \frac{\omega}{N} (\sin \gamma + \sin \mu). \tag{1}$$

where λ is the wave-length, ω the grating space, N the order of the spectrum, γ and μ the angles which the incident and diffracted light make with the normal to the surface at any point. This equation as developed by Rayleigh (loc. cit.) is deduced for parallel beams of light falling on a plane grating. Kayser (*Handbuch der Physik*) has shown that this holds also for a concave grating.

That is, if in Fig. 1 L is the radiant point, and if a cone of rays from L falling on the surface of the grating QoT at P is brought to a focus at L' by any means (if the grating is plane, a lens will be necessary), then λ is the wave length of the light which is brought to a focus at L'.

The above equation may be written:

$$(\sin\gamma + \sin\mu) = \frac{N\lambda}{\omega}. \qquad (2)$$

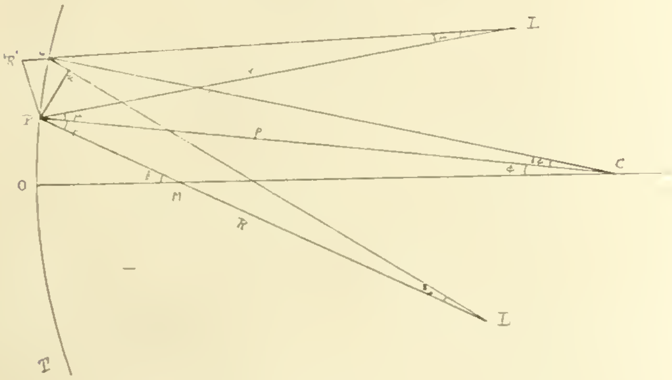


FIG. 1.

If now we allow the point P to move in the plane LoL', along the surface QoT, so that the angles which the incident and diffracted light make with the normal to the surface are now $(\gamma + \delta\gamma)$ and $(\mu + \delta\mu)$, then a new wave-length $(\lambda + \delta\lambda)$ will be brought to a focus at L' so as to satisfy the equation:

$$\sin(\gamma + \delta\gamma) + \sin(\mu + \delta\mu) = \frac{N\lambda}{\omega} + \frac{\delta(N\lambda)}{\omega}. \qquad (3)$$

Developing by Maclauren's theorem, and subtracting (2) we get:

$$\cos\gamma\,\delta\gamma + \cos\delta\mu = \frac{1}{\omega}\,\delta(N\lambda) \qquad (4)$$

in which we neglect quantities of an order higher than the first. Hence we get:

$$\cos\gamma\frac{d\gamma}{d\phi} + \cos\mu\frac{d\mu}{d\phi} = \frac{1}{\omega}\frac{d(N\lambda)}{d\phi}, \qquad (5)$$

where ϕ is any independent variable.

This equation gives the change in wave-length due to a change in the angles of incidence and diffraction, L and L' remaining unchanged.

If now the grating surface is spherical—the case of Rowland's concave grating—let o be the centre of the grating, c the centre of curvature; cP is the normal to the surface at P, and the line cP is the radius of curvature ρ. Then the angle LPc is γ, $L'Pc$ is μ, and putting ocP and oMP equal respectively to ϕ and θ, we see:

$$\gamma = \theta - \phi;\quad \mu = \theta' - \phi,$$

and hence

$$\frac{d\gamma}{d\phi} = \frac{d\theta}{d\phi} - 1;\quad \frac{d\mu}{d\phi} = \frac{d\theta'}{d\phi} - 1. \qquad (6)$$

Calling the distances LP and $L'P$ equal R and ν respectively, and letting fall perpendiculars PR and PR' on LQ and $L'Q$ respectively, we see that:

$$PR = \rho d\phi\cos\gamma = Rd\theta.$$

Hence

$$\frac{d\theta}{d\phi} = \frac{\rho\cos\gamma}{R},$$

and consequently,

$$\frac{d\gamma}{d\phi} = \frac{\rho\cos\gamma}{R} - 1;$$

and similarly

$$\frac{d\mu}{d\phi} = \frac{\rho\cos\mu}{\nu} - 1. \qquad (7)$$

Substituting these values of $\frac{d\gamma}{d\phi}$ and $\frac{d\mu}{d\phi}$ in equation (5) we get:

$$\cos\gamma\left(\frac{\rho\cos\gamma}{R} - 1\right) + \cos\mu\left(\frac{\rho\cos\mu}{\nu} - 1\right) = \frac{1}{\omega}\frac{d(N\lambda)}{d\phi}, \qquad (8)$$

which equation is true to terms of the order $d\phi$. Since this is the same equation as (5), it expresses the change in wave-length due to a change in the angle (ϕ) at the centre of curvature. To have a perfect focus at L', this change in wave-length due to a change in the angle ϕ must be zero, or in other words $\frac{d\lambda}{d\phi} = 0$. Light of wave-lengths which are whole multiples of λ will also be brought to the same focus L', since $\frac{d(2\lambda)}{d\phi} = 0$, $\frac{d(3\lambda)}{d\phi} = 0$, etc.

Hence, making $\frac{d(N\lambda)}{d\phi} = 0$, in (8) we have:

$$\cos\gamma\left(\frac{\rho\cos\gamma}{R} - 1\right) + \cos\mu\left(\frac{\rho\cos\mu}{\nu} - 1\right) = 0. \qquad (9)$$

This may be put in the form:

$$\frac{\cos^2\gamma}{R} + \frac{\cos^2\mu}{\nu} = \frac{\cos\gamma + \cos\mu}{\rho}, \qquad (10)$$

from whence we get:

$$\nu = \frac{R\rho\cos^2\mu}{R(\cos\mu + \cos\gamma) - \rho\cos^2\gamma}. \qquad (11)$$

This is the equation of the curve on which the spectra are brought to a focus. In this the centre of the grating is the origin, the line passing through the centre of curvature is the axis of reference, R and γ are the coördinates of the source of light, ν and μ the coördinates of the focal line. This is the same equation as derived by Rowland.

It should be noted that if "Rowland's mounting" is used (see below), the terms of the second order which are omitted in equation (4), vanish of themselves.

ASTIGMATISM.

One of the properties of the concave grating which has helped to make it of such great value in scientific research is the property of astigmatism, in virtue of which a point source of light at the slit is brought to a focus, not in a point but in a line. We consequently get a wide spectrum which renders the determination of wave-lengths more accurate, and increases the accuracy with which we can compare metallic and solar lines.

Although this property has always been recognized, no formula giving the amount of the astigmatism has been published, at least to my knowledge. This is deduced in the following formulae:

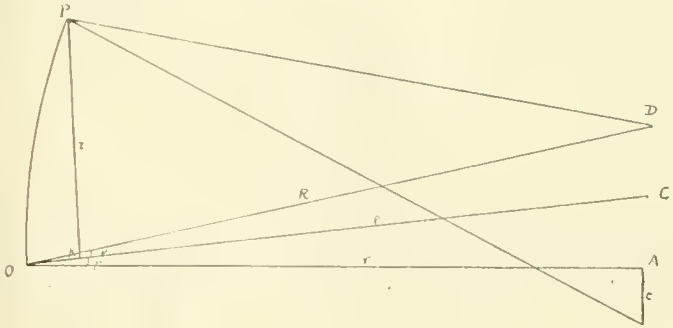


FIG. 2.

In Fig. 2 let D be the position of the point source of light at the slit, situated at a distance R from the centre of the grating O; AB is the spectral line under consideration, which will be parallel to the lines of the grating, and is situated at a distance r from the centre of the grating; C is the centre of curvature; CO is the radius of curvature ρ. AO and CO lie in a horizontal plane. Let PO be a vertical section of the grating; i. e., parallel to the lines of the grating. A small pencil of rays from the source D falling on the grating at O is brought to a focus at A, a small pencil from D falling on the grating at P is brought to a focus at B. It is our problem to find the length of AB, it being assumed that AB is perpendicular to OA.

Call $AB = c$, $PK = z$, where PK is the perpendicular let fall from P on the radius of curvature OC.

Since OK is a very small quantity compared with the other quantities considered:

$$OK = \frac{z^2}{2\rho} \quad \text{and}$$

$$AK = r - \frac{z^2}{2\rho}\cos\mu.$$

$$\overline{BP}^2 = \overline{AK}^2 + (\overline{KP} + \overline{AB})^2$$

$$= \left(r - \frac{z^2}{2\rho}\cos\mu\right)^2 + (z + c)^2.$$

If we neglect terms of a higher order than the second:

$$\overline{BP} = r - \frac{z^2}{2\rho}\cos\mu + \frac{z^2 + 2zc + c^2}{2r}.$$

Similarly we will have

$$\overline{DP} = R - \frac{z^2}{2\rho} \cos\gamma + \frac{z^2}{2R}.$$

But since the point of light at O, and the focal line AB are foci, the difference in paths of rays falling at P and at D must be zero. Hence

$$(AO + DO) - (BP + DP) = 0 \tag{12}$$

$$\text{i. e. } z^2\left(\frac{\cos\mu}{2\rho} + \frac{\cos\gamma}{2\rho} - \frac{1}{2R} - \frac{1}{r}\right) - \frac{cz}{r} - \frac{c^2}{2r} = 0 \tag{13}$$

Solving, we get:

$$c = -z \pm z\sqrt{r\left(\frac{\cos\mu + \cos\gamma}{\rho}\right) - \frac{1}{R}}. \tag{14}$$

Twice this value will give us the length of the spectrum when we have a point source of light at the slit.

But in practice the illuminated portion of the slit, assumed parallel to the lines of the grating, is of some finite length $2b$, where b is the length of the slit above the horizontal plane. To find the length (c') of the lines of the spectrum due to this, we have merely to apply the ordinary equation for finding the magnification due to a concave mirror, which in this case gives us:

$$\frac{c'}{r} + \frac{b}{R} = 0,$$

$$\text{or } c' = -b\frac{r}{R}. \tag{15}$$

Adding this to the value from equation (14), we have for half the length of the special lines:

$$c_0 = c + c' = -z \pm z\sqrt{r\left(\frac{\cos\mu + \cos\gamma}{\rho} - \frac{1}{R}\right)} - b\frac{r}{R}. \tag{16}$$

Apply this to the special case where Rowland's mounting is used. In this case slit, grating and camera are at the vertices of a right-angled triangle, and hence:

$$r = \rho;\ R = \rho\cos\gamma;\ \mu = 0.$$

Substituting these values in the above equation, we get:

$$c_0 = -\frac{b}{\cos\gamma} - z \pm z\sqrt{1 - \frac{\sin^2\gamma}{\cos\gamma}}.$$

As a special case, let $r = 0$. The image of the slit coincides with the slit itself, and hence $C_0 = -b$; whence we see that the positive sign before the radical must be used.

Hence,

$$c_0 = -\frac{b}{\cos\gamma} - z + z\sqrt{1 - \frac{\sin^2\gamma}{\cos\gamma}}.$$

From this equation it is seen that the astigmatism depends only on the length of the illuminated portion of slit, the length of the ruled lines of the grating, and the angle which the source of light makes with the axis of the grating. Astigmatism is independent of the radius of curvature.

Measuring the length of the lines of the spectrum formed by the large concave grating used in this University, it was found that the observed and computed values agreed most satisfactorily.

Influence of Surrounding Dielectric on Conductivity of Copper Wires. By J. F. Merrill.

Respecting the question discussed by Sanford, Carhart, Grimaldi and Platonia, and others, it was thought that a comparative method of measuring both temperature and resistances would give more satisfactory results than an absolute method, such as Sanford and Carhart employed.

Accordingly, two copper tubes each 100.7 cm. long and 3.2 cm. diameter, and each provided with a mercury thermometer graduated to tenths of degrees, a platinum thermometer, and about 39 feet of polished copper wire, 1 mm. diameter, wound in a helix 1.9 cm. diameter, extending from one end of the tube to the other, were placed side by side within a double walled tubular water jacket made of zinc. The pieces of wire in these tubes were cut from the same spool, and were of almost equal resistances. One tube was to be filled with air only, and the resistances of its various contents were to serve as standards, with which were to be compared those of the other tube, which was to be filled in turn with various dielectrics. These tubes were side by side in an air column, which was surrounded by a water column 8.5 cm. thick and 120 cm. high. The inner tube of the water jacket enclosing the copper tubes and the air column was 8.4 cm. in diameter and terminated at the bottom in a funnel, the stem of which, 8 cm. long and 1.2 cm. diameter, projected 1 cm. below the flat bottom of the water jacket. Up through this stem and funnel passed a rubber tube which connected with the inside of the dielectric tube, and through which liquids and vapors could be run in or out at will without in any way disturbing either of the copper tubes.

The mercury thermometer bulbs extended in about 6 cm. from the top of the tubes and served only as preliminary indicators of temperature The readings from these were not used in deducing results. Each platinum thermometer was made of 185 cm. of wire, .25 mm. diameter, doubled on itself and secured in a thin copper tube 9 mm. diameter and about 99 cm. long, which was fastened so as to pass lengthwise through the centre of the larger copper tube, but was insulated from it at both ends. Thus the platinum thermometer would indicate the average temperature of the tube in which it was placed. The copper helix, coiled about the smaller copper tube, was carefully insulated from it.

This helix was soldered to the cap at the bottom of the larger copper tube, but passed out through an insulating plug at the top. One copper tube and helix, or its platinum thermometer, formed one arm of a Jenkin bridge, while the other tube formed another. Connection was made with the bridge by means of heavy flexible cords terminating in rods, which were clamped to the bottom of mercury cups. The helix and one platinum terminal had a common lead from the tube to the bridge. Thus, to change from copper to platinum resistances, but one terminal at each side of the bridge had to be changed, together with the spool on which was wound the two fixed arms. These fixed arms, both for the platinum and the copper, differed by not more than 0.0003 ohms, the resistance of each arm for the copper resistances being about 0.30755 ohms at 27° C.—but little greater than the copper tube and helix. The air tube and helix and its platinum thermometer had slightly greater resistances than the corresponding ones of the dielectric tube; but a balance with the bridge was secured by shunting the greater resistance, using for this purpose standard plug boxes, a separate box for each; knowing the value of the shunt for each position of the bridge commutator and the value of the shunted resistances, the corresponding values of the dielectric tube could be calculated.

The water jacket was heavily wrapped with felt, and the bridge, shunt boxes, keys and galvanometer were enclosed in boxes and cases to prevent sudden changes of temperature in any part of the connections. The keys and commutators were operated by push rods and levers from the outside of the box. The galvanometer circuit was kept closed continuously, except during the instant of closing or opening the battery circuit, to avoid the disturbance due to thermal currents.

A careful determination of the temperature coefficient of each platinum thermometer gave, after annealing the wire, 0.00180. The coefficient for the copper tube and helix was 0.0037. After the tubes had stood in place several hours, surrounded by a nearly constant temperature water bath, measurements were made by means of a Queen's standard bridge, Anthony form, of the absolute resistance of the air tube and helix, and its platinum thermometer. The measurements gave for the tube and coil 0.27576 ohms, and for the platinum 7.3884 ohms at 22°.7 C. Observations were then taken at intervals during three days, water of nearly constant temperature running through the jacket night and day, to determine the difference between the resistances of the two tubes and their coils. The values for the second tube, air being the dielectric, were found to be 0.274279 and 7.37513 for copper and platinum respectively.

Kerosene at about the temperature of the bath was then run into the dielectric tube by the method indicated above, and measurements at intervals during three more days were made to determine the resistances. The observations during the second and third days are here given, those of the first day being equally good.

Let R' be shunt value when commutator was in one position, and R'' the value when in the other position; T, temperature in box enclosing bridge; T_1, temperature of air tube as given by mercury thermometer, and T_2, temperature of dielectric tube; R, the resistance deduced from the observations. The observations are here given in the order taken. To change from copper to platinum the bridge terminals were changed, as above indicated.

Date.	Hr.	T	T_1	T_2	R'	R''	R	
Aug. 10	*A. M.*				*Pt.*			
	10:55	24.4	22.59	22.59	4255	3880		
					4250	3875		
					4240	3880		
					4248	3878	7.37495	
					Cu.			
	11:15	24.4	22.60	22.60	51.7	49.29		
					51.32	49.33		(*A*)
					51.70	49.50		
					51.55	49.45		
					51.56	49.4	0.274264	
	P. M.				*Cu.*			
	3:10	24.4	22.65	22.65	51.9	49.78		
					51.63	49.38		
					51.86	49.66		
					51.8	49.6	0.274268	
					Pt.			(*B*)
	3:45	24.4	22.65	22.65	4260	3890		
					4260	3885	7.37500	
Aug. 11	*A. M.*				*Cu.*			
	8:00	23.6	22.3	22.3	52.45	50.33		
					52.26	50.24		
					52.00	50.00		
					51.96	50.10		
					51.85	50.10		
					52.1	50.15	(1)	
					Pt.			
	8:40	23.7	22.35	22.35	4325	3945		
					4320	3935		
						3935		
					4322	3937	(*a*)	
					Pt.			
	10:10	23.8	22.4	22.4	4340	3950		
					4335	3945		
					4337	3947	(*b*)	
					Cu.			
	10:20				51.85	50.5		
					51.85	50.3		
					51.90	50.5		
					51.70	50.2		
					51.90	50.3		
					51.84	50.36	(2)	
					Cu.			
	11:00	23.8	22.4	22.4	52.4	50.85		
					52.4	50.75		
					52.4	50.8	(3)	
					Pt.			
	11:05				4370	3975		
					4360	3970		
					4360	3965		
					4363	3967	(*c*)	

Date.	Hr.	T	T_1	T_2	R'	R''	R
Aug. 11	*A. M.*				*Cu.*		
					52.3	50.48	
	11:18				51.9	49.65	
					52.0	50.1	
					52.6	49.7	
					52.0	50.0	
					52.16	50.0	(4)
	P. M.				*Cu.*		
	3:35	23.8	22.4	22.4	52.00	49.65	
					52.25	50.2	
					52.5	50.55	
					52.6	50.25	
					52.3	49.9	
					52.33	50.11	(5)
					Pt.		
	3:55				4325	3950	
					4310	3945	
					4300	3930	
					4300	3925	
					4300	3920	
						3920	
					4307	3931	(*d*)
					Cu.		
	4:15	23.9	22.4	22.4	51.4	49.85	
					51.5	49.50	
					51.6	49.8	
					52.0	49.4	
					51.75	49.75	
					51.65	49.66	(6)

From set of observations (*A*) the platinum resistance in the dielectric tube is 0.00018 ohms less than the air value, corresponding to 0°.015 C. The copper resistance is 0.274264, but corrected for 0°.015 C. it is 0.274279, the exact air value. Correcting (*B*) in same way the result is 0.274278, same as in air.

The mean of (1, 2, 3, 4, 5, 6) gives $R' = 52.1$ and $R'' = 50.2$, from which is obtained 0.2742805 for R.

Mean of (a, b, c, d) gives $R' = 4332$ and $R'' = 3945$, from which is obtained for R 7.37520 ohms.

Now these values are almost identical with those obtained with air in the dielectric tube, the copper being 0.0000015 ohms greater and the platinum 0.00007 ohms greater, which corresponds to 0°.005 C. This would give for copper corrected 0.274285, an increase of 0.002 per ct., according to these observations.

Now for a copper connection a change of one ohm in R' corresponds to a possible resistance change of about 0.000025 ohms in the dielectric tube and helix. But a change of one ohm caused a galvanometer deflection of 22 scale divisions; hence a deflection of 1 scale division would be caused by a resistance variation of one millionth of an ohm. With the platinum where $R' \equiv 4350$ ohms, a change of five ohms would correspond to 0.00002 ohms, i. e., to about 0°.0016 C.

Sanford reported a *decrease* of resistance in kerosene of 0.18 per cent., which would correspond in the tube and wire here used to 0.00049 ohms. The sensibility of the galvanometer in these measurements was such that it seems if there had been a change of even 0.00001 ohm, or one-fiftieth of Sanford's percentage change, it certainly could have been detected. And notwithstanding the variations in the shunt resistances as given above the extreme difference corresponds only to 0.000015 ohms. But these variations were undoubtedly due mostly to variable commutator- and terminal-contacts.

Tests were made with other dielectrics and on another sample of wire of the same size with the following results. Let C_1 be first wire and C_2 the the second.

Dielectric.	*Possible Change less than*
Kerosene ………………… C_1	+ 0.002 per ct.
Absolute alcohol………. C_1	— 0.001 per ct., 1st test. — 0.001 per ct., 2d test.
C_2	+ 0.008 per ct., 1st sample alcohol (not pure). + 0.002 per ct., Squibbs' alcohol.
Absolute alcohol vapor.. C_1	+ 0.01 per ct., possibly, not probably, 1st test. + 0.009 per ct. possibly, not probably, 2d test.
Ether vapor……………. C_1	— 0.006 per ct., 1st test. + 0.002 per ct., 2d test.
C_2	+ 0.003 per ct.
Gasoline vapor………… C_2	— 0.005 per ct.
Benzine (petrolic ether) C_2	+ 0.005 per ct.
Benzine vapor………… C_2	— 0.002 per ct.
Chloroform vapor……… C_2	+ 0.002 per ct.

With the apparatus used the experimental error is not greater than 0.01 per ct. And it is fair to say that outside the limits of experimental error the dielectric does not change the conductivity. With slight modifications the method is capable of still greater accuracy.

The above work was begun in Baltimore and completed in the Ryerson Laboratory of the University of Chicago.

The Effect of Fibrous Structure in Iron on its Change in Length when Magnetized. By E. Rhoads.

The experiments described in this paper have for their object the determination of the effect which the grain, or fibrous structure of sheet iron, exerts upon its changes in length due to magnetization. Strips 3 x 91.5 cm. were cut from a long sheet of transformer iron 0.035 cm. thick, parallel with, and at right angles to, its length. These were bent into tubes around a bar, and measurements were made of the changes in length of each when subjected to a uniform magnetic field in the direction of its length. The accompanying magnetization was also measured.

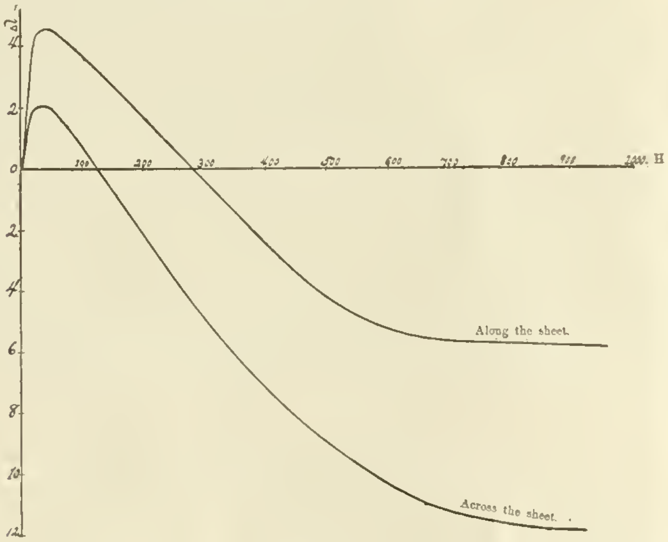
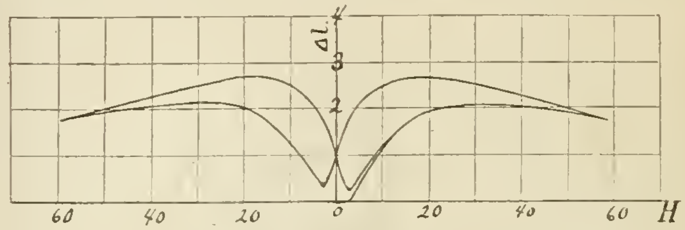


Fig. 1.

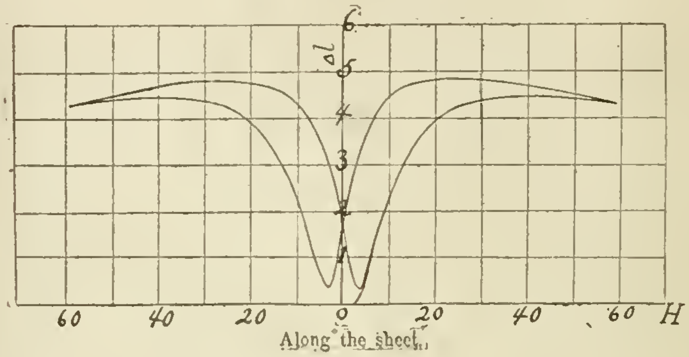
The method consists in hanging a specimen tube coaxially inside a shorter brass tube, to which it is clamped at the lower end. By means of a lever and tilting mirror, changes in their relative lengths may be measured accurately. The magnetic field is excited by a long solenoid, inside which the two tubes hang. The apparatus is a modification of that which has been in use in this laboratory for several years, and was described in *Phil. Mag.*, Vol. 40, p. 345, by Dr. More. (See also *Univ. Circ.*, June, 1897.)

The differences found in the magnetic changes in length, according as the grain runs parallel with, or at right angles to, the length of the specimen, are great, as will be seen in the accompanying curves. The curves in Figure 1 show the changes in length for one specimen of each kind under a cyclic magnetic force between limits of about 60 C. G. S. The curves in Figure 2 show the changes in increasing fields extending up to much higher values. The ordinates are plotted in both cases in millionths of the original length. The abscissae are plotted in C. G. S. units of magnetic field.

The effect of annealing the specimens was to make the maximum length occur in a lower field, and to greatly increase the retentiveness for change of length. The amount of the maximum increase is not affected in specimens cut at right angles to the length of the sheet, but it was greatly diminished in those cut parallel to it.



Across the sheet.



Along the sheet.

Fig. 2.

It is evident from these results that the changes in volume caused by magnetization in a specimen possessing a fibrous structure are dependent upon that structure; and therefore the question is once more opened, whether there would be any such change in an isotropic specimen.

The values of the intensity of magnetization were slightly higher in the same fields for specimens cut parallel to the sheet than for those cut across it.

Determination of Atmospheric Resistance at Speeds of 200 to 500 Miles an Hour. By A. F. Zahm.

There has been some discussion as to the law of atmospheric resistance at speeds between 100 and 1000 feet a second, some writers maintaining that it increases directly as the speed, others that it increases as the square of the speed, while still others hold that it increases as the cube of the speed or according to some more complex relation. These discrepancies are doubtless chargeable to the measuring devices; for, although superb apparatus has been employed for speeds below 100 miles an hour, no method seems ever to have been developed for the direct purpose of measuring resistance at higher speeds. Hence the only data we have for this region are those obtained in the practice of exterior ballistics, which, besides being devoted, for the most part, to speeds above 1000 feet a second, essays, primarily, to determine the *velocity* of projectiles rather than their resistance, a problem which is immensely more difficult.

The resistance is calculated from the rate of change of velocity, or the retardation, and this the ballistic methods have hitherto failed to measure accurately, mainly for the following reasons: (1) the projectiles used in gunnery are too dense; (2) the experiments are usually made outdoors, and hence in more or less wind; (3) the "screens" offer resistance and yield an unknown amount before complete rupture; (4) the chronographs have, until recently, been inaccurate.

The purpose of the research here outlined was to produce a reliable method of measuring the retardation of projectiles and by it to obtain the velocity-resistance curves, for speeds of 50 to 500 miles an hour, of a variety of simple geometrical forms, particularly of the sphere, spheroids, cylinders and other figures of revolution. The work so far accomplished has been to measure the resistance to spheres moving with velocities varying from 300 to 700 feet per second.

A chronograph was designed which offers no resistance to the projectiles, and which, with due care, measures its velocity accurately to less than $\frac{1}{100}$ of one per cent.; hollow projectiles were used which were about 40 times lighter than solid steel ones, thus making the retardation 40 times greater and consequently the resistance measurable with much greater accuracy the experiments were made indoors and in homogeneous still air.

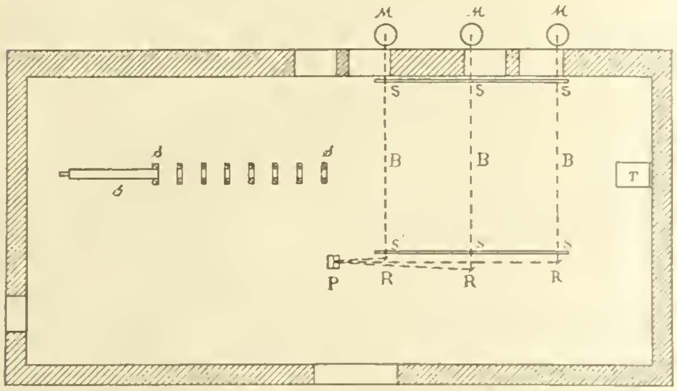


Fig. 1.

The general arrangement of the apparatus is shown in Fig. 1. The ball from the gun, *G*, passes through eight blast-screens, *S–S*, onward through still air, cutting three recording sunbeams, *B*, *B*, *B*, and lodges uninjured in a barrel of cotton, *T*. The sunbeams springing from the mirrors *M*, *M*, *M*, pass through gauge-slits *s*, *s*, *s*, *s′*, *s′*, *s′*, $\frac{1}{100}$ of an inch wide, strike the reflectors *R*, *R*, *R*, then pass through a camera lens to focus on a photographic plate, *P*, which falls freely during the bullet's flight. Thus as the ball cuts the sunbeams their tracings on the plate are instantaneously and momentarily interrupted, thereby revealing the bullet's time of transit from beam to beam, whence its velocity and resistance can be computed.

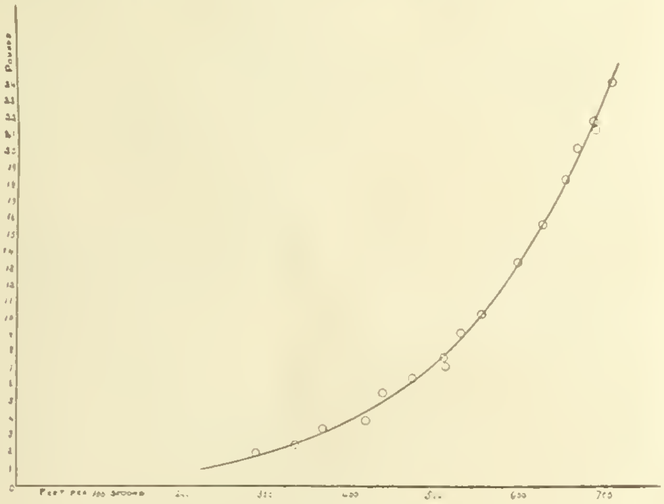


Fig. 2.

The camera is a columnar cast-iron box 5 feet high, 3 by 5 inches inside section, and provided with interior side grooves down which a massive iron bar drops freely, carrying with it a photographic plate 2 feet high by $2\frac{1}{2}$ inches wide, on which are focused the sunbeams through a lens in the side of the box 2 feet from its top. At the bottom of the camera is a cushion which yields to the impact of the falling mass so as not to endanger the plate. After each fall of the plate the camera may be displaced sidewise, say $\frac{3}{16}$ of an inch, while the shutter and lens remain stationary; thus it is possible to take a dozen or more records on one plate. Outside and back of the camera is a trigger whose mechanism drops the plate, opens the shutter and fires the gun at preadjusted time intervals.

The only bullets so far used have been polished four-inch ash spheres, some solid, others hollow of $\frac{1}{2}$ inch wall thickness. The balls are shot by smokeless powder from a 7-foot brass tube of $\frac{1}{8}$ inch wall thickness.

The photographic record of each shot is three fine vertical lines, each having a sharp interruption caused by the eclipse of its tracing sunbeam. The distance of each midbreak from the bottom of the photographic line is measured on a dividing engine and the corresponding time of fall of the plate calculated on the assumption that the resistance to descent is negligible. $t=\left(\frac{2h}{g}\right)^{\frac{1}{2}}$. (This assumption is rendered valid by making the plate-holder many hundred times heavier than its resistance to falling.) The distances between the sunbeams are accurately measured, and hence the mean velocity between each eclipse may be calculated. The retardation in 1 sec. is then deduced; and this, multiplied by the mass of the bullet, gives the force of resistance due to the air.

The accompanying table gives the values obtained from the first series of observations, which, as shown in Fig. 2, give a fairly smooth velocity-resistance curve. The quantities are accurate to less than 1 per cent.

Velocity and Resistance of Sphere $3''\frac{63}{64}$ Diameter.

Velocity. Ft. per Sec.	Resistance. Lbs. Wg.	Velocity. Ft. per Sec.	Resistance. Lbs. Wg.	Velocity. Ft. per Sec.	Resistance. Lbs. Wg.
438	5.58	555	10.24	286	1.91
688	21.60	512	7.09	333	2.49
473	6.39	628	15.47	367	3.43
417	3.87	691	21.09	599	13.25
510	7.61	656	18.16	691	23.89
531	9.09	670	20.00		

The curve given is considerably steeper than the nearest parabola of the family $R=aV^2$ and much more nearly coincides with one of the family $R=aV^3$, its true form probably being given by a more complex expression. When further records have been taken at higher and lower speeds the equation of the corrected curve may be sought with more profit than that of the present one.

The Concave Grating for Stellar Photography. By Charles Lane Poor and S. Alfred Mitchell.

The concave grating has proved a most powerful instrument for spectroscopic research, but heretofore it has not been successfully applied to stellar spectroscopy. During the past winter experiments have been carried out with a view of thoroughly testing the various methods of using the concave grating for astronomical purposes. The methods originally suggested by Professor Rowland were developed by Dr. Poor, and the apparatus constructed under his direction; the photographs were made by Mr. Mitchell.

There are two radically different methods for using the concave grating for stellar work:

First, in connection with an objective; the grating merely replacing the ordinary stellar spectroscope. This was tried by Professor Crew at the Lick Observatory in 1892 and a few results obtained.

Second, direct; the grating is the objective and the spectroscope combined: the light from the star being reflected directly from the grating to the photographic plate. This method was first developed by Dr. Poor in 1891, when a few experiments were made. No definite results were then obtained, however. Experiments were resumed in October last, and some promising photographs have since been obtained.

This paper contains a few notes in regard to the second method. The apparatus for mounting the grating is extremely simple, consisting of a light box clamped to the tube of the equatorial, the telescope being used merely as a finder. The light from the star falls directly on the grating, is diffracted and brought to a focus on the photographic plate. The grating is mounted in an ordinary holder, which can be adjusted by side and back screws. The plate holder holds a plate 1 x 5 inches, bent as closely as possible to the proper curve. The holder is capable of adjustment, so that the plate and the grating can be made parallel. The box is clamped to the telescope in such a way that the lines of the grating are parallel to the equator; and accordingly by regulating the driving clock of the telescope to run a little too fast or too slow, the spectrum can be made of any convenient width.

The advantages of this method of working are many. Among them may be mentioned, first, the spectrum is normal; second, great extent of ultra violet, as the light does not pass through any absorbing medium; third, simplicity of mounting and accuracy of following; fourth, ease of determining absolute wave lengths and motion in the line of sight.

Two gratings were experimented with as follows:

A. Two (2) inch concave grating; ruled surface 1 x 2 inches; radius of curvature 1 metre; ruled with 15,000 lines to the inch.

B. Six (6) inch concave grating; ruled surface 2 x 5¾ inches; radius of curvature 1 metre; ruled with 7,419 lines to the inch.

With grating A the photographs were made with the first order spectrum, with the grating B the second order was used. Seed's gilt edge plates and Cramer's isochromatic plates were used. Details of a few specimen plates follow.

With small grating:

Nov. 27, Sirius.—Exposure 40 minutes; width of spectrum, 1.5 mm. Plate shows eight hydrogen and H and K lines.

Jan. 3, Sirius.—Exposure 40 minutes; width of spectrum, 0.1 mm. Plate shows 16 hydrogen, H, K and about 15 other lines.

With large grating:

April 2, Vega.—Exposure 10 minutes; width of spectrum, 0.2 mm. Plate shows fourteen hydrogen and K lines.

April 5, Procyon.—Exposure 38 minutes; width of spectrum, 0.4 mm. Plate shows eleven hydrogen, K and about twenty other fine lines.

April 6, Capella.—Exposure 40 minutes; width of spectrum, 0.4 mm. Plate shows F, G, h, H, K and about 125 lines between F and H.

The Structure of the Shading of the "H and K" and Some Other Lines in the Spectrum of the Sun and Arc. By L. E. Jewell.

Several years ago while examining a series of photographs of the solar spectrum made by Professor Rowland in 1888 and 1889, I discovered one plate on which the shading of the H and K lines (due to calcium vapor) was broken up into bands or series. In each case the bands began at the centre of the shaded lines and extended outward, the distance apart of the component lines of the series increasing as the distance from the centre increased. In each case the series were perfectly symmetrical about the centres of H and K, and the individual lines or components of the series somewhat nebulous, while nearly all other small lines in the same region were sharp, clear lines.

All other plates available were carefully examined without the presence of series being indicated. Possibly a very few of the stronger lines in the series may be present upon most plates, but these lines may be merely approximately coincident and not connected with the series. A great many plates of this region of the spectrum have been taken by myself during the last few years over the centre of the sun, at the sun's limb, over sunspots, and under various conditions; but the presence of these series has never been certainly indicated. It is probable that the principal reason for this is that all the plates taken during several years past have been upon commercial plates which are coarse grained, thus masking the faint lines of the series, while the plate upon which they are shown is almost grainless.

There are several plates taken in the third order spectrum which show the shading of some of the strongest of the iron lines broken up into series; but the component lines are faint, nebulous, and close together. There are also suspicions of the partial resolution of the shading of the strongest lines of some other elements, but it is less certain.

All plates taken of the arc spectrum of the calcium lines H, K and g (λ = 3933.809, 3968.620 and 4226.892) have been carefully examined without any result until the 11th of last March, when a plate taken under somewhat special conditions showed the shading broken up into series.

I had for a number of years suspected that the shading of lines was produced by the overlapping of many series, all converging towards the principal line, but that under ordinary circumstances it is impossible to separate any series from the others (a possible exception occurs in the shaded lines of tin, which are plainly resolved into series).

It was thought probable that the distance apart of the lines in any particular series depended upon the degree of crowding of the molecules or density of the gas producing the shaded lines, and consequently the damping of the original vibration.

In both the electric arc and the sun's atmosphere we probably have layers of metallic vapors of varying degrees of density, so that the combination will generally produce a smooth shading, gradually increasing in intensity towards the central line.

In the case of the solar spectrum plate under consideration, it was thought that the slit of the spectroscope probably covered a region of the sun's atmosphere where the principal layer of calcium gas was of a particular density, and being thus to a large degree isolated, it was able to produce its characteristic series. This idea is somewhat confirmed by the fact that the general shading of H and K on the plate is unusually weak. These particular conditions would probably be most likely to occur over faculae.

On March 11th, having occasion to photograph the arc spectrum of calcium at λ 4000, I took several plates under widely different conditions. One plate shows the shading of H on the red side quite distinctly broken up into series similar to those of the solar spectrum plate mentioned. The resolution into series on the violet side is less distinct, while the shading of K shows the resolution better upon the violet than upon the red side, though not so distinctly as upon the red side of H.

The resolution into lines is hardly perceptible close to the principal line, but is fairly distinct about three Ångström units from H. In the solar spectrum plate the lines of the series are much more distinct nearer the central line (about 1 or 2 Ångström units away), and become too faint to follow at any great distance. They are much more distinct each side of K than around H.

In the arc spectrum plate it is also to be noted that the lines of the series are reversed, or absorption lines instead of emission lines, although at some distance away from the central lines it is probable that the series are continued as faint emission lines.

The arc spectrum plate showing these series was obtained by using an extremely powerful direct electric current, allowing it to act for a short time before throwing the image of the arc upon the slit of the spectroscope, and then exposing for three or four seconds only. Under these conditions the calcium was rapidly volatilized and the highly heated vapor formed a much more extended atmosphere around the poles than with a weaker current, and it is also possible that the conditions throughout the larger part of the arc were more uniform than under ordinary circumstances.

Announcements of Courses in the Johns Hopkins University for the academic year beginning October 1, 1898, may be had on application to the Registrar of the University.

A detailed statement of the Courses in Physics and in Applied Electricity may also be obtained on application.

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CONTENTS.

PAGE.
Notes from the Physical Laboratory:
Some New Methods for the Measurement of Self Inductance, Mutual Inductance and Capacity. By H. A. Rowland and T. D. Penniman, - - - - - - 51
Electric Absorption in Condensers. By H. A. Rowland and T. D. Penniman, - 52
Some Notes on the Zeeman Effect. By J. S. Ames, R. F. Earhart and H. M. Reese, - - - - - - - - - - - - - - - - - - 53
The Effect of Alternating Current Wave-Forms on Transformer Losses. By Louis Duncan, W. L. Hodges, F. B. Keidel and E. Frank, - - - - - - 53
A Re-calculation of Griffiths' Mechanical Equivalent of Heat, based on Kahle's Determination of the Absolute Electro-Motive-Force of a Clark Cell and of the Electro-Chemical Equivalent of Silver. By F. A. Wolff, Jr., - - - - - 54
The Energy Spectrum of an Absolutely Black Body. By C. E. Mendenhall and F. A. Saunders, - - - - - - - - - - - - - - - - - 55
A Re-calculation of Rowland's Values of the Mechanical Equivalent of Heat. By C. W. Waidner and F. Mallory, - - - - - - - - - - - - - - 55
Notes on the Concave Grating. By S. Alfred Mitchell, - - - - - - 56
Influence of Surrounding Dielectric on Conductivity of Copper Wires. By J. F. Merrill, - - - - - - - - - - - - - - - - - - 58
The Effect of Fibrous Structure in Iron on its Change in Length when Magnetized. By E. Rhoads, - - - - - - - - - - - - - - - 60
Determination of Atmospheric Resistance at Speeds of 200 to 500 Miles an Hour. By A. F. Zahm, - - - - - - - - - - - - - - - - - 60
The Concave Grating for Stellar Photography. By C. L. Poor and S. Alfred Mitchell, - - - - - - - - - - - - - - - - - - 61
The Structure of the Shading of the "H and K" and some other Lines in the Spectrum of the Sun and Arc. By L. E. Jewell, - - - - - - - - - 62
Recent Publications in Physics, - - - - - - - - - - - - - 63

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I. American Journal of Mathematics.

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